Exclusion fences reduce colonization of carrots by the carrot rust fly, *Psila rosae* (Diptera: Psilidae)

ROBERT S. VERNON and ROBERT R. MCGREGOR[1]

PACIFIC AGRI-FOOD RESEARCH CENTRE, AGRICULTURE and AGRI-FOOD CANADA, P.O. BOX 1000, AGASSIZ, BC, CANADA, V0M 1A0

ABSTRACT

The effectiveness of exclusion fences in preventing the colonization of carrot plantings by the carrot rust fly, *Psila rosae* (F.), was tested in small field plots. Fenced enclosures were surrounded by panels of mesh nylon window screen 120cm high. Control enclosures were left unfenced. Although the number of first generation *P. rosae* adults captured on yellow sticky traps was not significantly different between control and fenced enclosures, the number of second generation adults emerging within enclosures was significantly higher in control enclosures than in fenced enclosures. The percentage of unmarketable carrots, % damaged carrots, % unmarketable yield, % damaged yield, and number of lesions per carrot were all significantly higher in control enclosures than in fenced enclosures. We conclude that exclusion fences impede the colonization of carrot plantings by *P. rosae* and reduce damage to carrots. The results are discussed as they relate to pest management methods for the carrot rust fly.

Key words: *Psila rosae*, carrot rust fly, physical control, exclusion fences

INTRODUCTION

The carrot rust fly, *Psila rosae* (F.), is the most common and injurious insect pest of carrots grown in Europe and North America (Dufault and Coaker 1987). To control this pest, commercial growers normally apply insecticides throughout the growing season. In British Columbia (BC), up to nine sprays per field have been reported per season (Judd *et al.* 1985), and up to seven sprays per season have been reported in Ontario (Stevenson 1981). Similar spray regimes in Europe often result in less than adequate control (Esbjerg *et al.* 1983). Although population-monitoring-based integrated pest management programs have dramatically reduced spraying of carrots in Canada (Judd *et al.* 1985), insecticides remain the primary management method for *P. rosae*. Because of the loss of available insecticides through deregistrations and pest resistance, the development of alternative control methods for management of *P. rosae* and other root-feeding Diptera is essential. This paper reports on the testing of an exclusion fence as a physical control for management of carrot rust fly.

Cultural and physical control methods for the management of *P. rosae* have previously been developed. Planting of carrots at strategic times of the year (Ellis and Hardman 1988), planting in low-risk areas along with proper crop rotations (Kettunen *et al.* 1988), or the use of resistant varieties (Ellis and Hardman 1988), have been used by organic growers to reduce damage. To date, physical control methods have been limited to the use of row covers which reduce damage by *P. rosae* and other vegetable pests such as the cabbage maggot, *Delia radicum* (L.) (Haselli and Konrad 1987; Ellis and Hardman 1988; Folster 1989; Antill *et al.* 1990; Davies *et al.* 1993). However, row covers are usually considered impractical for use in North America because of the high costs of material, labour, deployment and management.

---

[1] Current address: Department of Biology, Douglas College, P.O. Box 2503, New Westminster, BC, V3L 5B2

Vernon and MacKenzie (1998) recently described the use of an exclusion fence for retarding the colonization of rutabagas by cabbage maggots. A 120cm high fence of window-screen mesh with a 22cm downward-sloping mesh overhang at the apex reduced the entry of *D. radicum* females and subsequent maggot damage in small plantings of rutabagas. It was suggested that exclusion fences could be used for control of *D. radicum* in other cruciferous crops like cabbage, broccoli, cauliflower and Brussels sprouts. Because crop rotation is a common practice in vegetable production, it would be desirable to use permanently-erected exclusion fences against major insect pests of crops planted in rotation with crucifers, such as carrots.

The use of exclusion fences for insect control relies on the assumption that no resident population exists and immigrating insects travel below the top of the exclusion fence. Oviposition within fenced plantings of a crop is prevented when low-flying females are excluded by the fence. Both *D. radicum* (Vernon 1979; Tuttle *et al.* 1988) and *P. rosae* (Judd *et al.* 1985) have been shown to fly near the top of the canopy within fields of their respective host plants. It has also been reported that *P. rosae* migrates in and out of carrot fields during the course of the growing season. Because of these tendencies for low-elevation flight and within-season migration, it is likely that movements of *P. rosae* into a crop would be impeded by exclusion fences and that the rate of oviposition within fenced plantings would be reduced.

In this study, we tested the efficacy of exclusion fences for management of *P. rosae* in field plots of carrots. In particular, we compared colonization by adult *P. rosae* and emergence of second-generation progeny between field plots that were fenced and unfenced. In addition, we compared several measures of carrot damage between fenced and unfenced plots.

MATERIALS AND METHODS

Fence design. The exclusion fence consisted of 1mm mesh nylon window screen panels (210cm long by 120cm high) (Stollco Industries Ltd.) oriented vertically and supported by wooden fence posts (7.5cm by 10cm by 120cm high, Figure 1). Panels were connected together such that they surrounded the field plots. At the top of each panel, a wooden fence top (2cm high by 8cm wide by 210cm long) was placed on the top edge of the aluminum panel frame. Along the wooden fence top, a 60cm wide strip of 1mm mesh nylon window screen was attached such that 25cm of screen was exposed on either side of the fence and was angled downward at 45° on both sides (Figure 1). The mesh overhangs were secured by plywood triangles attached to the tops of the fence posts. The overhangs were intended to retard intercepted flies from moving up and over the fence. All fence components, including the mesh screens, were black in colour.

Description of field site. The study was conducted in 1993 in a 4 hectare commercial field located at Cloverdale, BC. The field had a highly organic muck soil, and a history of high populations of *P. rosae* along the western edge of the field. The western edge of the field was characterized by tall trees and stinging nettles (*Urtica dioica* L.) which are commonly associated with high populations of *P. rosae* (Wainhouse and Coaker 1981). On 20 April, four parallel beds of carrots cv. Six Pak were precision seeded in a north-south direction along the western edge of the field. Each bed had four rows of carrots with 45cm between the rows, and 1.8m between adjacent bed centres. The carrots were separated from the underbrush at the western edge of the field by a 10m strip of grass which was mowed every 2 weeks. The rest of the field was seeded with onions beginning about 10m to the east of the carrots. The plots were sprayed once on 15 May with linuron for weed control, and were hand-weeded thereafter.

Experimental design. Fences were erected between 30 April and 4 May; each was 8m by 8m, and enclosed 8m sections of the four beds of carrots. Control plots were identical in size and had the fence framework erected alone without the vertical mesh but including the mesh overhangs. Fenced and control plots were arranged in a randomized complete block design with four replicate blocks. Paired treatments within blocks were separated by a distance of 8m, and

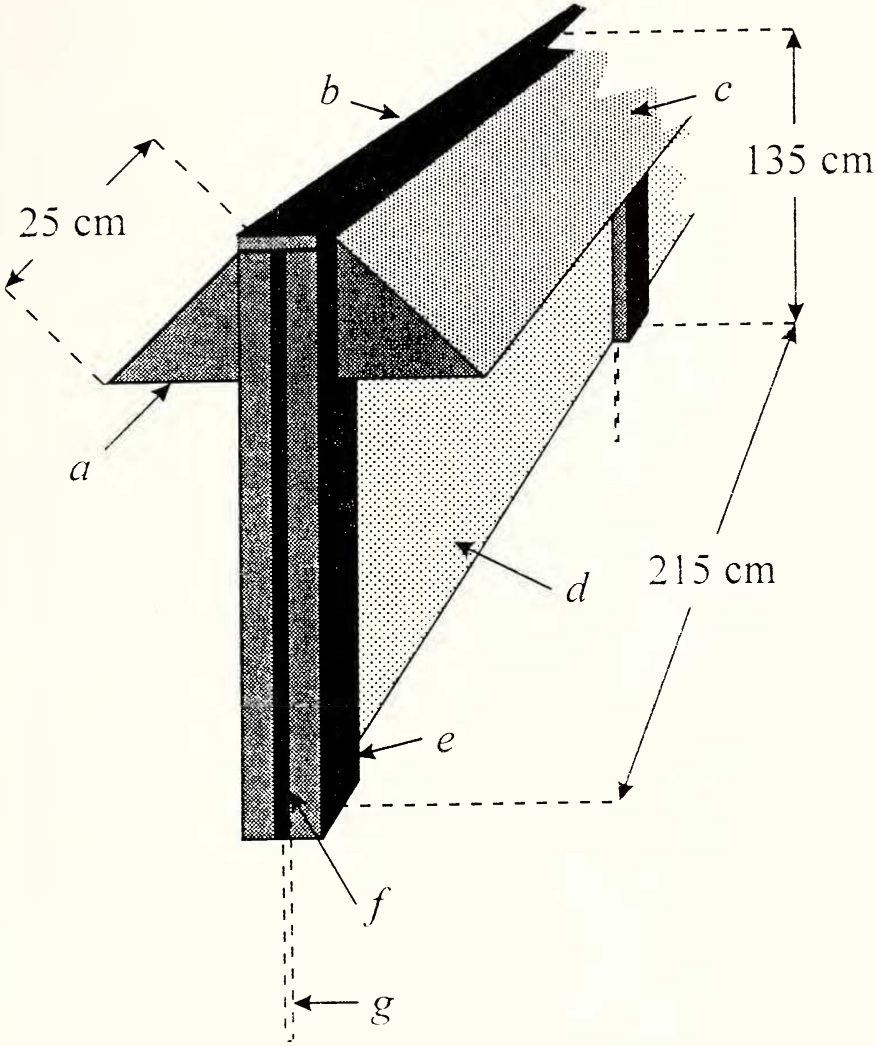

Figure 1. Design of exclusion fences with 25cm overhangs. Fence components include (a) overhang support wing, (b) wooden fence top, (c) mesh overhang, (d) mesh screen, (e) hollow wooden fencepost, (f) groove in post for screen, and (g) rebar to anchor post.

replicate blocks were separated by at least 10m. Fences were removed from all experimental and control plots on 16 September.

P. rosae trapping. Yellow sticky traps (11 by 14cm, Vernon *et al.* 1994) coated on both sides with Sticky Stuff (Olson Products, Medina, OH) were used to sample adult *P. rosae* within fenced and control plots. Single traps were placed on wooden stakes in the center of each fenced or control enclosure on 4 May. The tops of the traps were set initially at 20cm above the ground, and were raised in height during the season as the crop grew. The traps were oriented to face north and south and were located between the second and third beds of carrots. Traps were replaced on 21 and 25 May, 1, 4, 7, 14, 17, 22, and 28 June, 5, 12, 20, and 27 July, 3, 10, 17, and 25 August, and 1, 10 and 16 September. The number of adult *P. rosae* on traps returned to the laboratory were counted and recorded as the number of *P. rosae* captured per enclosure per trapping period. Trap captures before 5 July were from the first (overwintered) *P. rosae* generation of 1993, and trap captures after 12 July were from the second generation of 1993.

Between 13 and 15 July, 6 wooden emergence pyramids (Giles 1987) were placed in each fenced and control enclosure to measure the emergence of the second generation of *P. rosae*. The emergence pyramids were boxes constructed of plywood in the shape of a pyramid, 100cm long and 30cm wide, and fit with a collecting jar at the apex. Pyramids were centered 2, 4 and 6m along each of the middle two beds of carrots. Each pyramid straddled the two middle rows of carrots in each bed. To facilitate the placement of the pyramids, carrots occupying about 30cm of row at the start and end of the pyramid were removed. The foliage of the remaining carrots under the pyramids was clipped to about 10cm, and the pyramids were sealed with soil along the base. *P. rosae* adults that emerged into plastic vials atop the pyramids were removed and counted on 17, 19, 21, 23, 25, 27, 29 and 30 July, and 1, 3, 4, 6, 8, 10, 12, and 17 August. Counts for the six pyramids within each enclosure were totalled for each sampling date and recorded as the number of *P. rosae* that emerged per enclosure per trapping period.

Carrot damage assessment. Carrots were harvested on three dates to compare levels of damage between fenced and control enclosures. On 13-14 July, the carrots removed to facilitate placement of emergence pyramids were retained as a damage sample. On 11 August, samples of carrots were taken 1, 3, 5, and 7m along the westernmost of the two central beds in each fenced and control enclosure. The samples consisted of 10 carrots taken from the middle row of the bed in areas not covered by emergence pyramids (for a total of 40 carrots per enclosure). On 20 September, samples of 25 carrots each were taken 2 and 4m along the middle row of the bed located farthest west in each enclosure.

Samples of carrots from all three dates were examined and classified as marketable or unmarketable. Marketable carrots had no lesions, or a single, inconspicuous lesion that would not be obvious to consumers. Unmarketable carrots had one or more conspicuous feeding holes present. The percentage of unmarketable carrots was calculated for each enclosure for each sample date.

For samples from 11 August and 20 September, carrots were divided into those that were marketable and unmarketable. Carrots from these two categories were weighed as groups. The yield (total weight of all carrots in each sample), mean weight per carrot (yield divided by the number of carrots in the sample) and percentage of the yield in the unmarketable category were calculated. For the sample from 20 September, the number of feeding sites on each carrot was counted and recorded as the number of lesions per carrot.

Statistical analysis. All trap capture data from yellow sticky traps were square-root transformed (i.e. sqrt $(X + 0.5)$) before analysis. Trap capture data from the first generation of *P. rosae* (21 May to 5 July) and the second generation (12 July to 16 September) were analysed separately. The number of *P. rosae* adults captured on sticky traps in particular trapping sessions throughout the season was compared between fenced and control enclosures using repeated-measures analysis of variance (ANOVA). The total number of *P. rosae* adults captured by emergence pyramids in each enclosure on particular collection dates was compared between fenced and control enclosures using repeated-measures ANOVA for the entire season's data, and using t-tests for individual sample dates. Proportional measures of carrot damage were arcsine transformed before analysis (i.e. arcsin(sqrt (X)). The percentage of unmarketable carrots, % yield unmarketable, mean weight per carrot, and number of lesions per carrot were compared between fenced and control enclosures by t-tests separately for data from different sample dates. Means and standard errors of all transformed variables were back-transformed for reporting purposes. All statistical analyses were conducted using Systat for Windows, Version 5.0 (Wilkinson *et al.* 1992).

RESULTS

P. rosae trapping. More first generation *P. rosae* were captured on sticky traps in control enclosures than in fenced enclosures, but this difference was not statistically significantly (Table 1). Similarily, more second generation *P. rosae* adults were captured in control enclosures than in fenced enclosures, but this was difference was not statistically significant (Table 1). The mean number of *P. rosae* adults captured in emergence pyramids was significantly higher in control enclosures than in fenced enclosures when data for the entire season was analysed (Table 1). When data were analysed for individual sample dates, the mean number of *P. rosae* captured in emergence pyramids was significantly higher in control enclosures than in fenced enclosures for 8 of the 16 sample dates (Figure 2).

Table 1

Trap captures on yellow sticky traps and captures from emergence pyramids of *Psila rosae* per trapping period in fenced and unfenced enclosures (Mean ±SE). Means in rows followed by the same letter are not significantly different by repeated-measures ANOVA (p>0.05).

Trapping method	*P. rosae* generation	Treatment: Control	Treatment: Fenced	*F*	df	*p*
Yellow sticky traps	First	0.5 ± 0.2 a	0.1 ± 0.1 a	2.97	1,6	0.14
Yellow sticky traps	Second	1.4 ± 0.3 a	0.9 ± 0.2 a	1.40	1,6	0.28
Emergence pyramids	Second	5.5 ± 0.5 a	1.5 ± 0.2 b	20.29	1,6	0.004

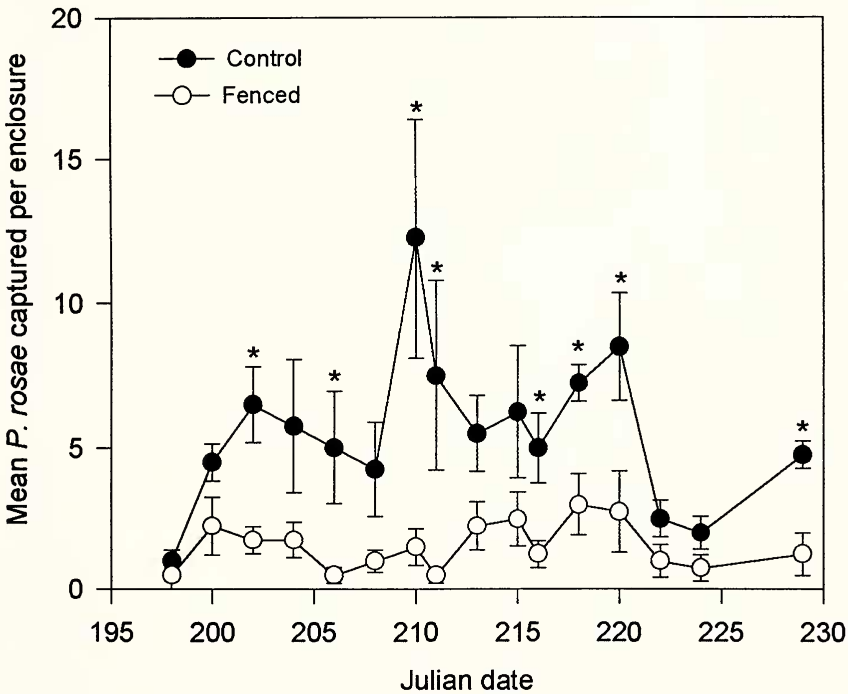

Figure 2. Mean number of *P. rosae* adults captured in emergence pyramids within fenced and unfenced enclosures on 16 sample dates in 1993. Dates where significant differences in captures between fenced and control enclosures were detected by t-tests (at p<0.05) are marked by an asterix. Error bars indicate standard errors of means.

Carrot damage assessment. The percentage of unmarketable carrots was significantly higher in control enclosures than in fenced enclosures for damage samples taken on 11 August and 20 September (Table 2). The percentage of yield unmarketable was also significantly higher in control enclosures for the samples of 11 August and 20 September (Table 2). However, the mean weight per carrot was not significantly different between fenced and control enclosures for either of these sample dates (Table 2). Finally, the number of lesions per carrot was significantly higher for control enclosures than for fenced enclosures for the sample of 20 September (Table 2).

Table 2

Damage to carrots caused by *Psila rosae* in fenced and unfenced enclosures (Mean ±SE). Means in rows followed by the same letter are not significantly different by t-tests (p=0.05).

		Treatment			
Sample date	Variable	Control	Fenced	t	p
13 July 93	% Unmarketable	3.2 ± 1.5 a	0.5 ± 0.3 a	2.2	0.07
11 August 93	% Unmarketable	8.1 ± 3.3 a	0.6 ± 0.6 b	3.3	0.02
	% of yield unmarketable	10.9 ± 6.8 a	0.6 ± 0.6 b	2.5	0.05
	Weight per carrot (g)	71.9 ± 3.9 a	94.3 ± 11.1 a	1.9	0.10
20 Sept. 93	% Unmarketable	87.0 ± 5.8 a	38.7 ± 12.9 b	3.3	0.02
	% of yield unmarketable	91.9 ± 4.8 a	47.7 ± 14.2 b	3.1	0.02
	Weight per carrot (g)	134.8 ± 13.2 a	149.6 ± 19.6 a	0.6	0.55
	Lesions per carrot	4.8 ± 0.8 a	0.7 ± 0.3 b	4.6	0.004

DISCUSSION

Although no statistical differences could be detected between mean captures of adult *P. rosae* on sticky traps in fenced *vs.* control enclosures, the emergence of second generation progeny was significantly lower in fenced enclosures than in control enclosures. This suggests that *P. rosae* females entering the field were prevented from colonizing the plots by the fences, resulting in decreased oviposition within fenced enclosures. Carrot damage was also substantially reduced within fenced enclosures compared to control enclosures. These data indicate that exclusion fences show considerable promise as a management method for carrot rust fly.

Captures of *P. rosae* on sticky traps in the first generation of 1993 were very low. However, the amount of damage resulting from colonization of carrots by even this moderately-low population of *P. rosae* was substantial in control plots (3.2%). Currently no economic injury level for carrots in BC has been defined, but damage levels greater than 5% usually draw attention during the grading process (R. Vernon, personal observation). The level of protection of carrots provided by exclusion fences has the potential to substantially reduce damage caused by this pest. The use of exclusion fences in combination with cultural controls might be an effective management strategy for *P. rosae*. For example, careful timing of carrot planting and harvest dates to avoid periods with the maximum damage potential could be combined with the use of exclusion fences.

Although carrot damage in fenced enclosures was always lower than in control enclosures, the level of damage recorded in fenced enclosures on the final sampling date was above what is tolerable for commercial carrot production. The damage recorded in the final sampling date was caused by the progeny of second generation *P. rosae* that emerged within the plots. If these carrots had been harvested before the flight period of second generation *P. rosae* occurred, much of this damage would have been prevented.

Exclusion fences have been shown to impede the colonization of rutabagas by the cabbage maggot, *D. radicum* (Vernon and MacKenzie 1998). The fences will likely also protect plantings of other brassica crops from damage by *D. radicum*, and could possibly prevent damage to plantings of onions by the onion maggot, *Delia antiqua* (Meigen) (R.S. Vernon, unpublished data). If exclusion fences are effective against a variety of pest species that attack different vegetable crops, it may be practical to erect permanent fences around vegetable fields where carrots, onions and brassicas are planted in rotation. The effectiveness of exclusion fences for management of carrot rust fly and other vegetable pests in large commercial fields remains to be tested.

ACKNOWLEDGEMENTS

We thanks Reg Ens and J. Mackenzie for help with the field work and damage assessments, Paul Garvin for plot maintenance and the donation of land for this study, and D. Raworth for manuscript review. This study was supported by a grant from Energy Mines and Resources (PERD program), and is submission number 582 of PARC Agassiz.

REFERENCES

Antill, D.N., D. Senior, J. Blood-Smyth, J. Davies and B. Emmett. 1990. Crop covers and mulches to prevent pest damage to field vegetables. Brighton Crop Protection Conference, Pests and Diseases 1: 355-360.

Davies, J.S., J.K. Hembry and G.H. Williams. 1993. Novel production systems to minimize pesticide use in intensive field vegetable crops. Crop protection in Northern Britain 1993: Proceedings of a conference. Dundee University, pp. 23-25.

Dufault, C.P. and T.H. Coaker. 1987. Biology and control of the carrot rust fly, *Psila rosae* (F.). Agricultural Zoology Reviews 2: 97-134.

Ellis and Hardman. 1988. Non-insecticidal contributions to an integrated program for the protection of carrots against carrot fly. Bulletin - SROP 9: 33-39.

Esbjerg, P., J. Jorgensen, J.K. Nielson, H. Phillipsen, O. Zethner and L. Olgaard. 1983. Integrated control of insects in carrots, the carrot rust fly (*Psila rosae* F., Dipt., Psilidae) and the turnip moth (*Agriotis segatum* Schiff., Lep., Noctuidae), as crop pest model. Tidsskrift for Planteavl 87: 303-356.

Folster, E. 1989. Pay attention to crop rotation even when using netting. Deutscher-Gartenbau 43, 11: 688.

Giles, K.I. 1987. Estimation of an economic threshold for the tuber flea beetle, *Epitrix tuberis* Gentner (Coleoptera: Chrysomelidae), on potato in British Columbia. Master of Pest Management Professional Paper, Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada.

Haselli, A. and P. Konrad. 1987. Regulating the incidence of pests with nets. Deutscher-Gartenbau 41, 31: 1806-1810.

Judd, G.J.R., R.S. Vernon and J.H. Borden. 1985. Commercial implementation of a monitoring program for *Psila rosae* (F.) (Diptera: Psilidae) in Southwestern British Columbia. Journal of Economic Entomology 78: 477-481.

Kettunen, S., I. Havukkala, J.P. Holpainen and T. Knuuttila. 1988. Non-chemical control of carrot rust fly in Finland. Annales Agriculturae Fenniae 27: 99-105.

Stevenson, A.B. 1981. Carrot rust fly: monitoring adults to determine whether to apply insecticides. Journal of Economic Entomology 74: 54-57.

Tuttle, A.F., D.N. Ferro and K. Idoine. 1988. Role of visual and olfactory stimuli in host finding of adult cabbage root flies. Entomologia Experimentalis et Applicata 47: 37-44.

Vernon, R.S. 1979. Population monitoring and management of *Hylema antiqua* and *Thrips tabaci* in British Columbia onion fields, with observations on other root maggot populations. Master of Pest Management Professional Paper, Simon Fraser Ur[illegible]ersity, Burnaby, BC, Canada.

Vernon, R.S. and J.R. MacKenzie. 199[illegible] e effect of exclusion fences on the colonization of rutabagas by cabbage flies (Diptera: Anthomyiid[illegible] Canadian Entomologist 130:153-162.

Vernon, R.S., J.R. MacKenzie and D.[illegible] 994. Factors influencing consistency of a carrot rust fly (Diptera: Psilidae) monitoring pro[illegible] Columbia. Environmental Entomology 23: 579-586.

Wainhouse, D. and T.H. Coaker. 19[illegible] ion of carrot rust fly in relation to the flora of field boundaries, pp. 263-272. In: J.[illegible] pathogens and vegetation. Pitman, London.

Wilkinson, L., M. Hill, J. P. Welna[illegible] 2. SYSTAT for Windows. Version 5. SYSTAT Inc., Evanston, IL.